CO_2 Sequestration Potential of Texas Low-Rank Coals

Quarterly Technical Progress Report

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ABSTRACT

The objectives of this project are to evaluate the feasibility of carbon dioxide (CO_2) sequestration in Texas low-rank coals and to determine the potential for enhanced coalbed methane (ECBM) recovery as an added benefit of sequestration. The main objectives for this reporting period were to (1) determine the effects of permeability anisotropy on performance of CO_2 sequestration and ECBM production in the Lower Calvert Bluff Formation (LCB) of the Wilcox Group coals in east-central Texas, and (2) begin reservoir and economic analyses of CO_2 sequestration and ECBM production using horizontal wells.

To evaluate the effects of permeability anisotropy on CO_2 sequestration and ECBM in LCB coal beds, we conducted deterministic reservoir modeling studies of 100% CO_2 gas injection for the 6,200-ft depth base case (Case 1b) using the most likely values of the reservoir parameters. Simulation results show significant differences in the cumulative volumes of CH_4 produced and CO_2 injected due to permeability anisotropy, depending on the orientation of injection patterns relative to the orientation of permeability anisotropy. This indicates that knowledge of the magnitude and orientation of permeability anisotropy will be an important consideration in the design of CO_2 sequestration and ECBM projects.

We continued discussions with Anadarko Petroleum regarding plans for additional coal core acquisition and laboratory work to further characterize Wilcox low-rank coals.

As part of the technology transfer for this project, we submitted the paper SPE 100584 for presentation at the 2006 SPE Gas Technology Symposium to be held in Calgary, Alberta, Canada on May 15-18, 2006.

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INTRODUCTION

The objectives of this project are to evaluate the feasibility of carbon dioxide (CO_2) sequestration in Texas low-rank coals and to determine the potential for enhanced coalbed methane recovery as an added benefit of sequestration. During this reporting period, we evaluated the effects of permeability anisotropy on performance of CO_2 sequestration and ECBM production in the Lower Calvert Bluff Formation (LCB) of the Wilcox Group coals in east-central Texas, and began reservoir and economic studies of CO_2 sequestration and ECBM recovery using horizontal wells in these coals.

EXPERIMENTAL

None.

RESULTS AND DISCUSSION

Coal Characterization

We continued discussions with Anadarko Petroleum regarding plans for additional coal core acquisition and laboratory work to further characterize Wilcox low-rank coals. We anticipate acquiring additional coal samples and beginning additional laboratory studies during the next quarter.

Reservoir Modeling Parameters

Simulation studies of Texas low-rank coals were conducted using coal properties and reservoir parameters obtained from literature and data collected during this study. Table 1 summarizes the model parameters selected to represent LCB reservoir coals at a depth of 6,200 ft.

Permeability anisotropy measured in a coal seam in the Bowen basin, Queensland, by a multiple interference test was 2.8:1.[1] This is considered to be a moderate degree of anisotropy, lying within the range of ratios measured at the Rock Creek site in the Warrior basin,[2] where measurements in three seams identified a well-developed anisotropy ratio of 17:1, a moderate anisotropy ratio of 2.3:1, and a virtually 1:1 isotropic case. A permeability anisotropy ratio of 4:1 was obtained from type curve analysis of a four-well injection interference test conducted at the Dartbrook Mine, in the Sydney coal basin, Australia.[3] We used permeability anisotropy ratios ranging from 1:1 to 8:1 for this sensitivity study (Table 1).

Reservoir Modeling

Permeability Anisotropy Analysis

To determine the impacts of permeability anisotropy on performance of CO_2 sequestration and ECMB production in Wilcox coals in east-central Texas, we conducted deterministic reservoir modeling studies of 100% CO_2 injection for the 6,200-ft depth coal seam scenario, using the most likely values of reservoir parameters, under the base case operating conditions. We used permeability aspect ratios of face cleat permeability (k_x) to butt cleat permeability (k_y) of 1:1, 2:1, 4:1 and 8:1. Results of the sensitivity study using a diagonal orientation and two parallel orientations are shown in Figs. 1-4.

We first simulated a diagonal orientation in which the line connecting producers with injectors is offset 45° with the permeability axes. Using this diagonal orientation, anisotropic permeability sensitivity studies for 100% CO_2 injection indicate that methane production and CO_2 injection rates decrease with increasing permeability aspect ratio (Fig. 1). There are no significant differences in the cumulative volumes of CH_4 produced or CO_2 injected due to increasing permeability anisotropy (Fig. 2). The primary differences are in project lives, with longer breakthrough times as injection rates decrease with increasing permeability aspect ratio. Breakthrough times for 80-acre patterns (40-acre well spacing) ranged from 1,460 days (4.0 years) to 1,700 days (4.7 years), for the reservoir parameters and permeability aspect ratios investigated. Simulation results indicate that LCB coals can store 1.75 to 1.69 Bcf of CO_2 at depths of 6,200 ft with an ECBM recovery of 0.67 to 0.71 Bcf and water produced of 74 to 79 Mstb, for permeability anisotropy ratios increasing from 1:1 to 8:1, respectively. Methane recovery factors range between 69.9% and 74.2% at breakthrough.

Next, we simulated a parallel orientation with face cleat permeability (k_x) aligned with the line connecting injector and producer wells. Grid orientation effects contribute to an earlier breakthrough time for the isotropic case for the parallel grid as compared to the diagonal grid. This prevents a direct comparison of diagonal orientations to parallel orientations; however, the variation in performance with anisotropy ratios for the respective orientations should still be relevant. For the parallel orientation with face cleat permeability (k_x) aligned with the injector and producer wells, there are significant decreases in the cumulative volumes of CH_4 produced and CO_2 injected due to increasing permeability anisotropy (Fig. 3). Gas injection and production rates increase with increasing permeability aspect ratio, causing rapid CO_2 breakthrough at the production well and hence reducing the cumulative volumes of CO_2 injected and CH_4 produced. Simulation results indicate that these coals can store only 1.37 to 0.63 Bcf of CO_2 at depths of 6,200 ft with an ECBM recovery of 0.51 to 0.23 Bcf, water produced of 67 to 46 Mstb, and CO_2 breakthrough time of 1,220 to 490 days, for permeability anisotropy increasing from 1:1 to 8:1, respectively. Gas recovery factors range between 54.1% and 23.5% at breakthrough, indicative of low sweep efficiency.

Using a parallel orientation with butt cleat permeability (k_y) aligned with the injector and producer wells, there are significant differences in the incremental volumes of CH_4 produced or CO_2 injected due to increasing permeability anisotropy (Fig. 4). Gas injection and production rates decrease with increasing permeability aspect ratio, causing longer CO_2 breakthrough times and increasing the cumulative volumes of CH_4 produced and CO_2 injected. Simulation results indicate that these coals can store 1.37 to 1.79 Bcf of CO_2 at depths of 6,200 ft with an ECBM recovery of 0.51 to 0.67 Bcf, water produced of 67 to 74 Mstb, and CO_2 breakthrough time of 1,220 to 2,620 days, for permeability anisotropy increasing from 1:1 to 8:1, respectively. Gas recovery factors range between 54.1% and 70.8% at breakthrough, indicative of improved sweep efficiency.

Based on these results for an 80-ac, 5-spot pattern, permeability anisotropy has potentially significant effects on carbon sequestration and ECBM projects due to the effects on injection and production rates, which will dictate CO_2 sequestration capacity and ECBM recovery. The degree and orientation of the anisotropy are influenced by the regional geology, i.e., structural trends, stress direction, and fracture orientation. Recognition of the magnitude and orientation of permeability anisotropy in coal reservoirs is important for optimal design and production practices.

Horizontal Well Analysis

Studies to date indicate that CO_2 sequestration and enhanced coalbed methane recovery using vertical wells in Texas low-rank coals is uneconomic to marginally economic. To determine if horizontal wells could improve performance, we began probabilistic reservoir and economic modeling studies using horizontal wells for both CO_2 injection and methane production. These studies are not yet complete and will be reported in the next quarterly report.

Technology Transfer

As part of our technology transfer obligations for this project, we submitted paper SPE 100584 for presentation at the 2006 SPE Gas Technology Symposium to be held in Calgary, Alberta, Canada on May 15-18, 2006.

CONCLUSIONS

Anisotropic permeability sensitivity studies for 100% CO_2 injection show significant differences in the cumulative volumes of CH_4 produced and CO_2 injected due to permeability anisotropy, depending on the orientation of injection patterns relative to the orientation of permeability anisotropy. This indicates that knowledge of the magnitude and orientation of permeability anisotropy will be an important consideration in the design of CO_2 sequestration and ECBM projects.

REFERENCES

1. Wold, M.B., *et al.*: "Anisotropic Seam Response to Two-Phase Fluid Injection into a Coalbed Methane Reservoir – Measurement and Simulation," paper SPE 36984 presented at the 1996 SPE Asia Pacific Oil and Gas Conference, Adelaide, Australia, 28-31 October.

2. Koenig, R.A.: "Interference Testing of a Coalbed Methane Reservoir," paper SPE 15225 presented at the 1986 SPE Unconventional Gas Technology Symposium, Louisville, KY, 18-21 May.

3. Wold, M.B. and Jeffrey, R.G.: "A Comparison of Coal Seam Directional Permeability as Measured in Laboratory Core Tests and in Well Interference Tests," paper SPE 55598 presented at the 1999 SPE Rocky Mountain Regional Meeting, Gillette, Wyoming, 15-18 May.

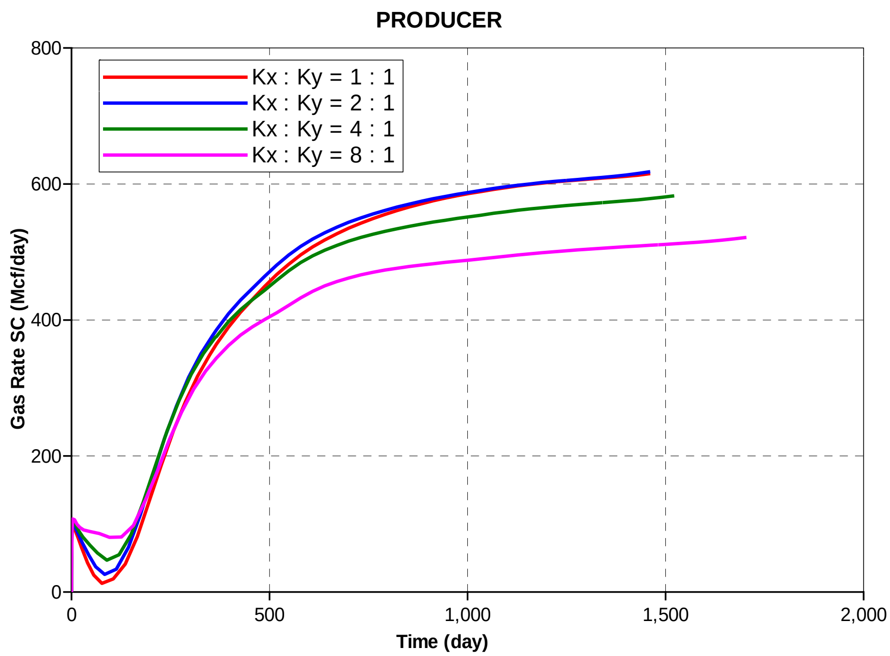
Table 1 – Summary of Reservoir Model Parameters

Static Coal Reservoir Model Parameters	
Parameter	**Value**
Fracture/Cleat Spacing	2.5 inches
Fracture Porosity	1%
Matrix Porosity	1%
Fracture Compressibility	138 e-6 1/psi
Water Density	0.99 g/cm^3 (61.85 lb/ft^3)
Water Viscosity	0.607 cp
Water Compressibility	4.0 e-6 1/psi
Initial Water Saturation	100%
Initial Composition of Gas in Reservoir	100% CH_4
Uncertain Reservoir Parameters and Design Parameters	
Parameter	**Value**
Coal Seam Thickness [(1)]	10, 20, 30 feet
Fracture Absolute Permeability [(2)]	0.8, 2.8, 10 mD
Coal Density [(1)]	1.289, 1.332, 1.380 g/cm^3 (80.5, 83.2, 86.2 lb/ft^3)
Gas Phase Diffusion Time [(1)] (Sorption Time)	0, 1, 4 days
Permeability Anisotropy Ratio	1:1, 2:1; 4:1, 8:1
Well Spacing	40-acre well spacing
Base Case 6,200-ft depth coal seam scenario	
Parameter	**Value**
Depth	6,200 feet
Initial Reservoir Pressure	2,680 psia
Reservoir Temperature	170 ^oF
Langmuir Isotherm Parameters [(3)] :	
V_L, CH_4	363.6 scf/ton
P_L, CH_4	608.5 psia
V_L, CO_2	961.9 scf/ton
P_L, CO_2	697.5 psia
V_L, N_2	166.1 scf/ton
P_L, N_2	2,060.7 psia
Operating Conditions - Pressure Control :	
Production Well, Pressure and Rate	40 psia, 3.5 MMscf/D
Injection Well, Pressure and Rate	3,625 psia, 3.5 MMscf/D

(1) Triangular Distribution

(2) Log-Normal Distribution

(3) As Received Basis



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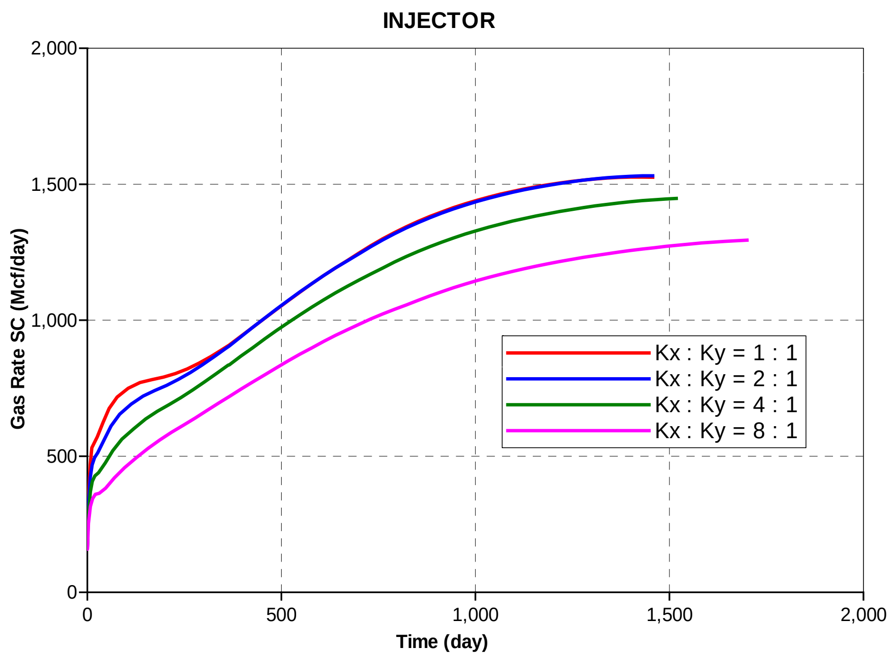

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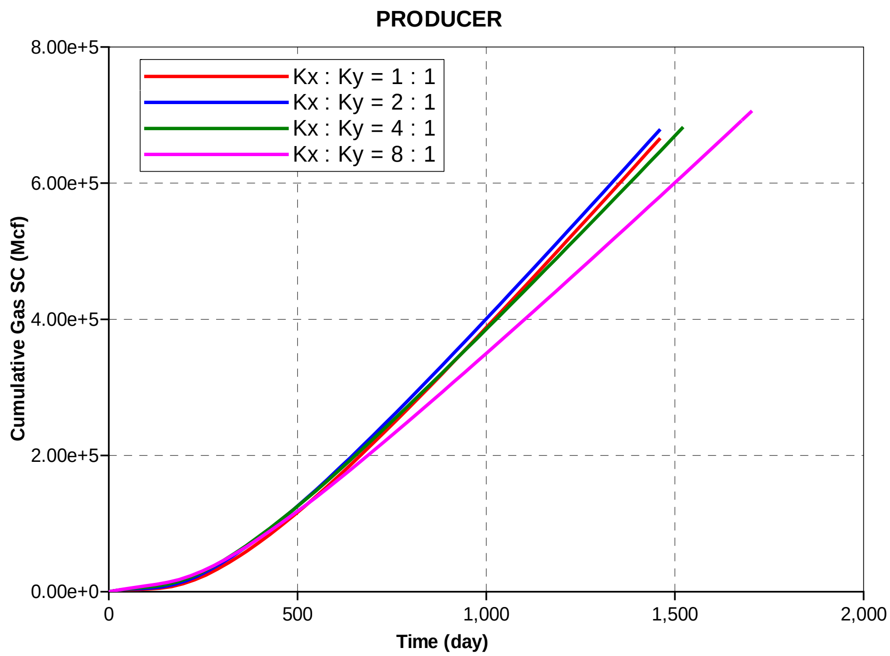
Fig. 1. Effect of permeability aspect ratio on (a) CH_4 production rates and (b) CO_2 injection rates, for the 6,200-ft depth coal seam scenario and the most-likely reservoir parameters, using a diagonal orientation (100% CO_2 injection). Volumes are for an 80-acre 5-spot pattern (40-acre well spacing).



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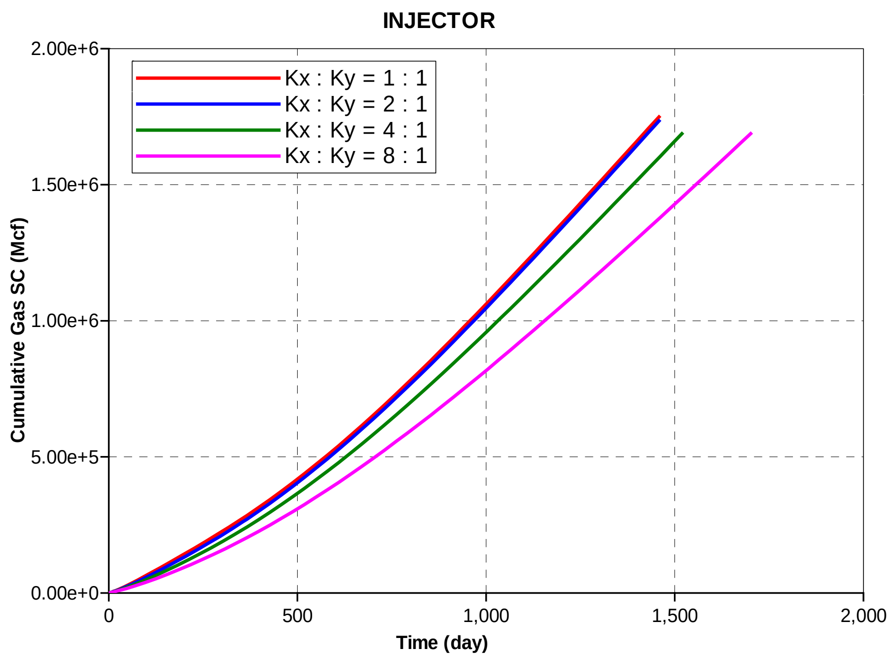
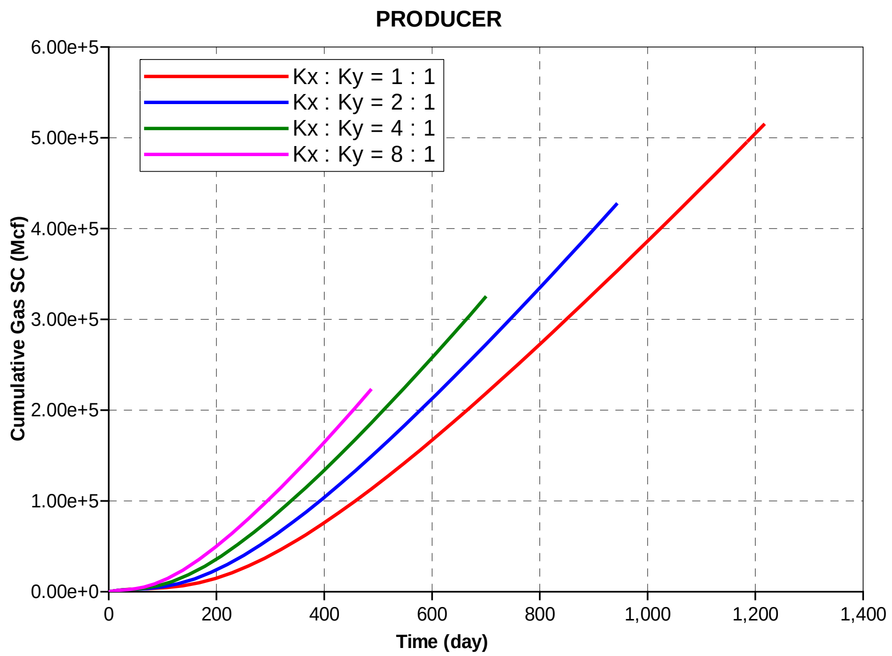


(b)

Fig. 2. Effect of permeability aspect ratio on (a) cumulative CH_4 production and (b) cumulative CO_2 injection, for the 6,200-ft depth coal seam scenario and the most-likely reservoir parameters, using a diagonal orientation (100% CO_2 injection). Volumes are for an 80-acre 5-spot pattern (40-acre well spacing).



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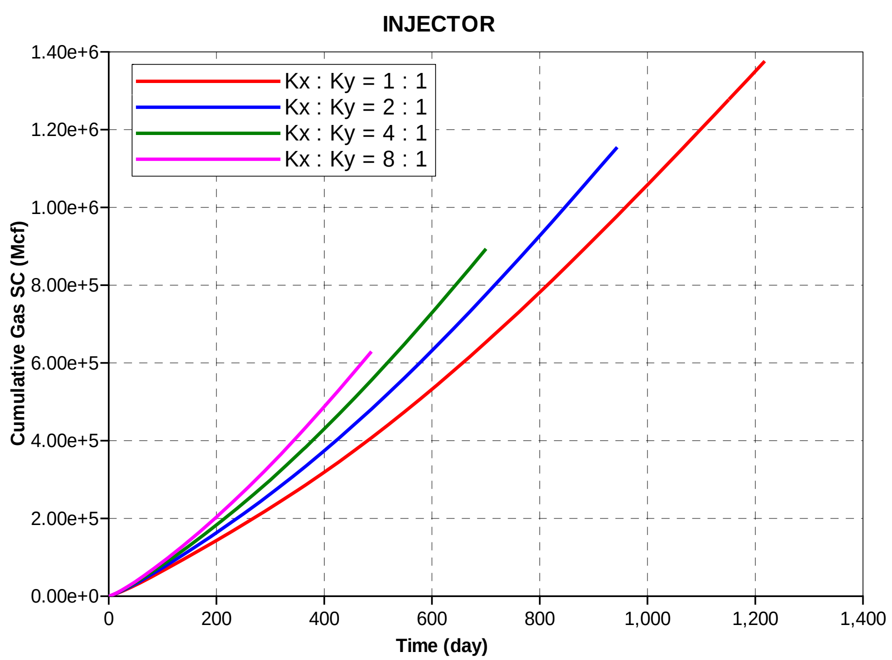
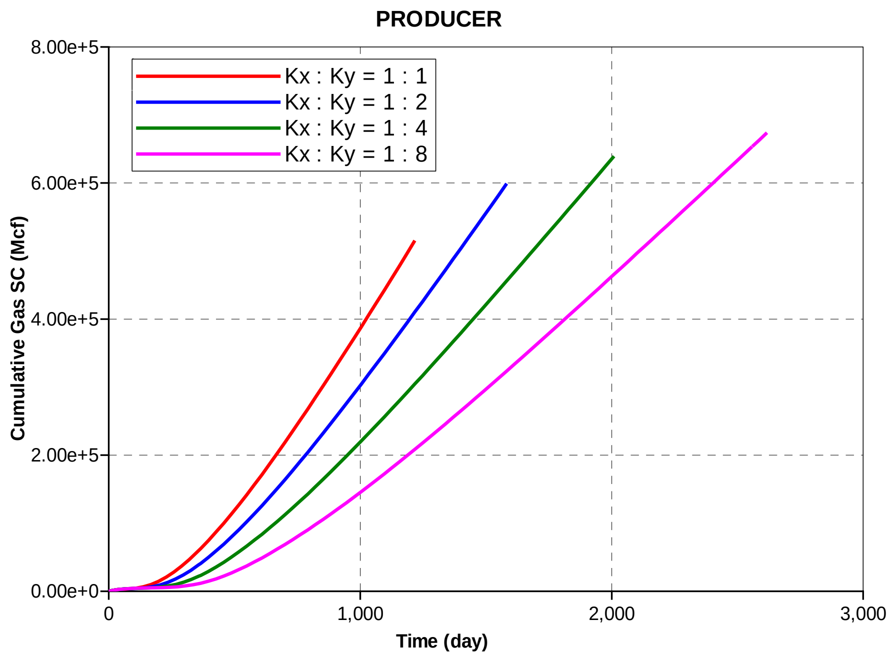


(b)

Fig. 3. Effect of permeability aspect ratio on (a) cumulative CH_4 production and (b) cumulative CO_2 injection, for the 6,200-ft depth coal seam scenario and the most-likely reservoir parameters, using a parallel orientation with face cleat permeability (k_x) aligned with the injector and producer wells (100% CO_2 injection). Volumes are for an 80-acre 5-spot pattern (40-acre well spacing).



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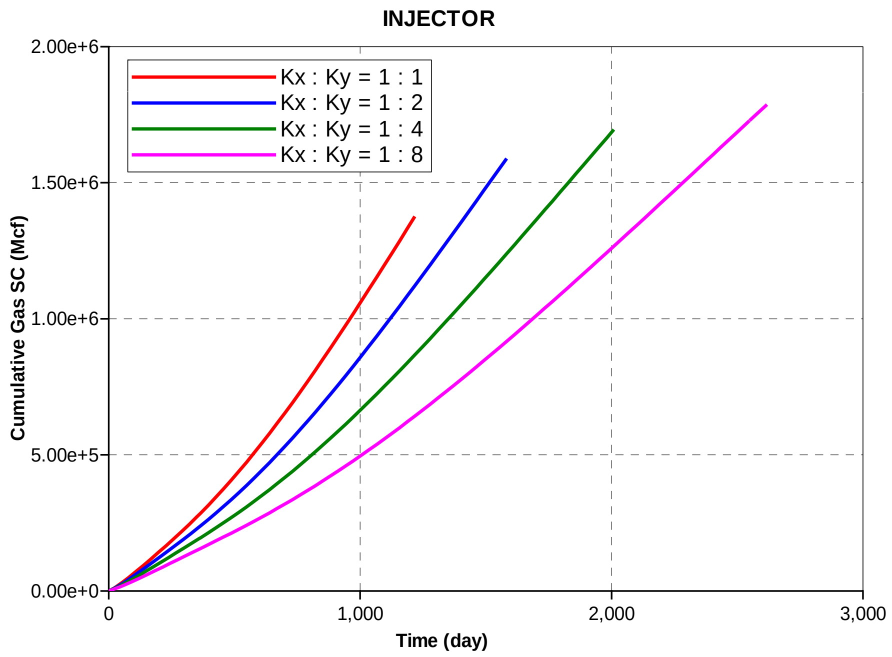

(b)

Fig. 4. Effect of permeability aspect ratio on (a) cumulative CH_4 production and (b) cumulative CO_2 injection, for the 6,200-ft depth coal seam scenario and the most-likely reservoir parameters, using a parallel orientation with butt cleat permeability (k_y) aligned with the injector and producer wells (100% CO_2 injection). Volumes are for an 80-acre 5-spot pattern (40-acre well spacing).